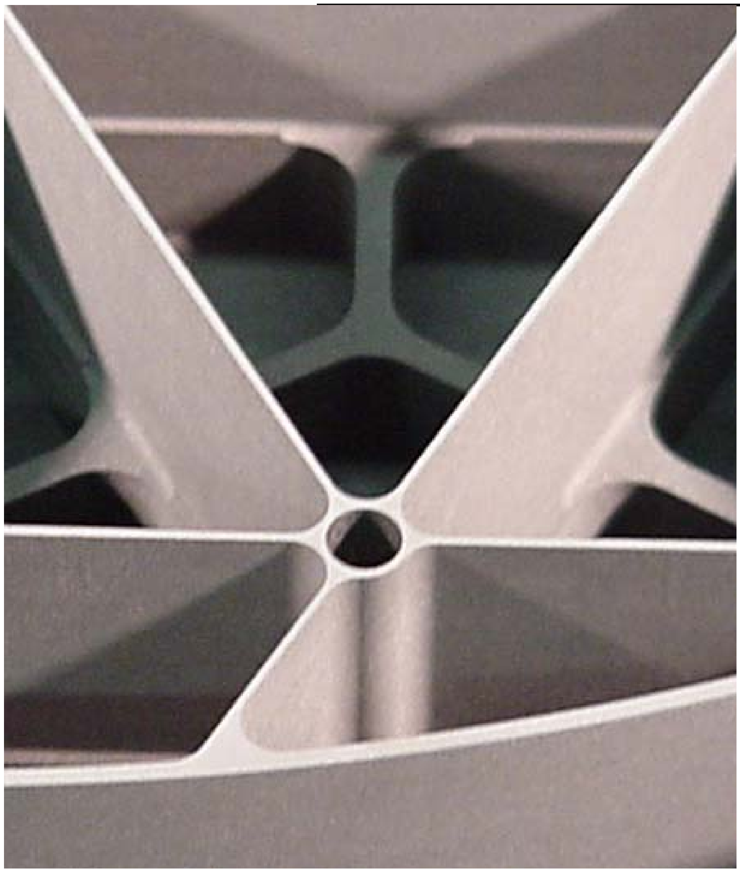
Preliminary Design of a Silicon Carbide Optical Bench Replacement for Beryllium



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Acknowledgements

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- Dr. Brett deBlonk was the technical monitor.

Presentation Outline

- **Background**
- **Project Goals**
- **Design Issues**
- **Design Approach**
- **Results**
- **Recommendations**
- **Acknowledgements**

Background - Optical Benches

- **With the significant interest in Silicon carbide for mirror applications, there is also an interest in SiC as an optical bench**
- **Cost and fabrication issues have prevented consideration of silicon carbide for optical benches in the past.**
- **Silicon carbide benches with silicon carbide mirrors enable high performance cryogenic optical telescopes.**
- **POCO CVC process is able to readily produce complex parts with little or no Silicon Carbide machining.**

Advantages of SiC

- Outstanding combination of thermal and mechanical properties
- Remarkable long-term dimensional stability even under the influence of extreme environmental conditions
- Silicon carbide has a very high specific stiffness
- Very high thermal conductivity combined with very low thermal expansion
- Competes with Be at cryogenic temperatures

Material Properties Comparison

Material	Density (ρ)	Elastic modulus (E)	Thermal expansion (α)	Thermal conductivity (κ)	Mechanical Figure of Merit (E/ρ)	Thermal Figure of Merit (κ/α)
Units	g/cm^3	GPa	$x\ 10^{-6}/K$	W/m-K	kN-m/g	$W/\mu m$
RBO SiC	2.89	391	2.4	31	135	12.92
CVD SiC	3.21	466	2.4	198	145	82.5
HP SiC	3.20	455	2.4	130	142	54.16
Beryllium	1.85	287	11.4	190	155	16.67
Zerodur ® (7)	2.53	91	0.05	1.64	36	32.80
BK7 (glass)	2.53	80.7	7.1	1.12	32	0.16
SXA	2.91	117	13.0	125	40	9.62
Aluminum	2.7	68	23.6	170	25	7.20
POCO SiC	2.55	218	2.4	153	85	64

POCO CVC Process

POCO Proprietary Graphite

Tolerance ±0.001"

Machining

Purification

Tolerance ±0.003"

Assembly

Convert Graphite Completely to beta SiC

Final Machining

+0.008" added

Coat Finished Part with CVD SiC

Grind & Polish Precision Optical Surfaces

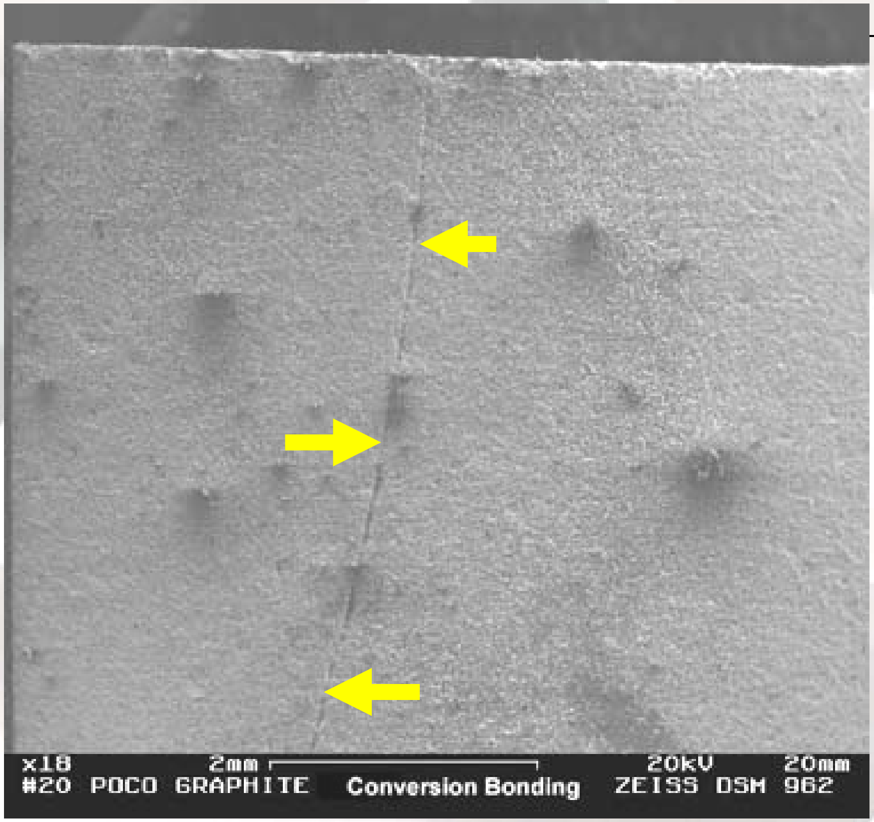
Advantages to Direct Machining and Conversion to SiC

- Can produce complex parts that are difficult, if not impossible to produce by other SiC processes.
- Very small and predictable growth means most tolerances can be met with no grinding required.
- High precision surfaces require only 0.002- 0.003” (50-75µm) of material removal.
- Direct machining of components means no molds or patterns are required.
- Direct machining and conversion means maximum flexibility, low $ for changes & small-lot production.
- Conversion bonding allows features such as closed backs to be incorporated into parts.

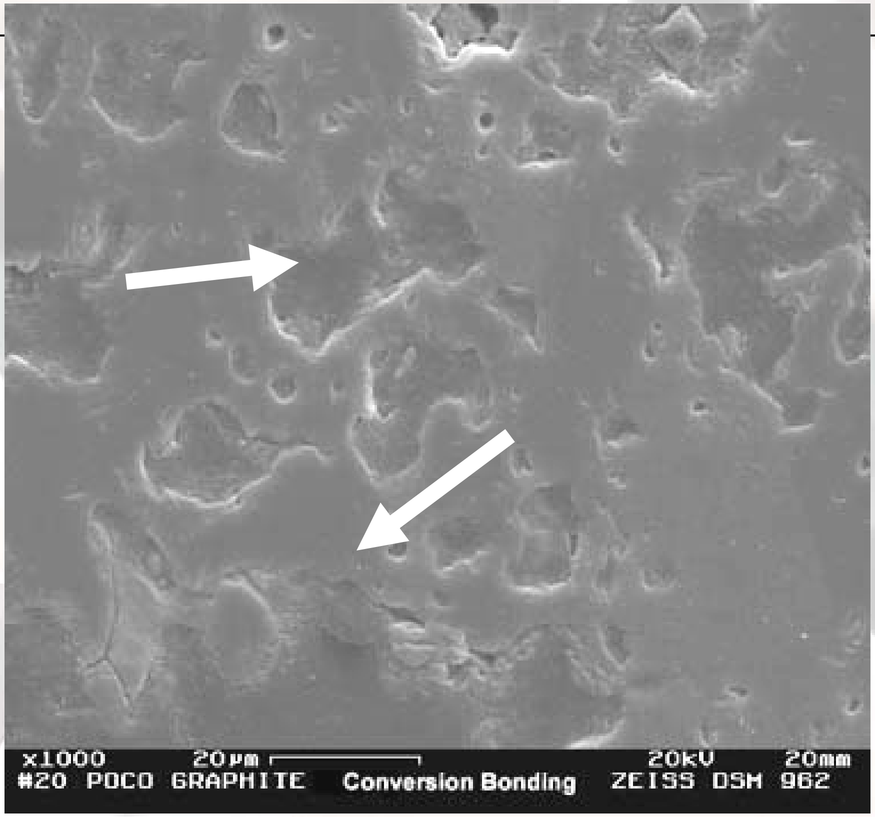
Conversion Bonding

- Poco has developed a “conversion bonding” process
- The SiC conversion bond has been demonstrated qualitatively to be as strong as a single (monolithic) SiC converted piece.
- This process allows
  - Closed back mirror construction
  - Mirror mounting
  - Allows scaling to large, monolithic mirrors and optics structures
- There appears to be no observable structural or morphological differences between the mated pieces and the seam. Higher magnification images show grain structure formation across the area of the seam. The mating pieces appear to be one unit/piece after conversion bonding.

Conversion Bonding



Arrows show the chamfered seam in the face view. The disk is on the left and the mating piece is on the right.



White arrow shows grain structure crossing the area of the seam.

Conversion Bonding

- **Closed back mirrors**
- **Mounting solutions**
- **Optical bench and support structures**

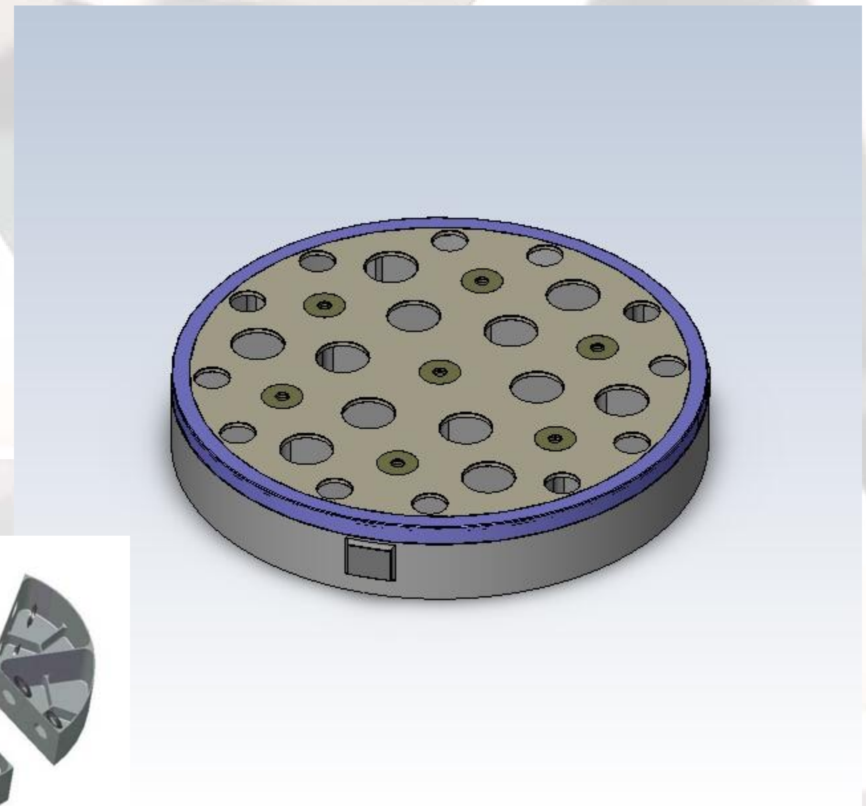


Figure 8. Bonding Components

Figure 9. Exploded View of Assembly

Goal of Phase I Project:

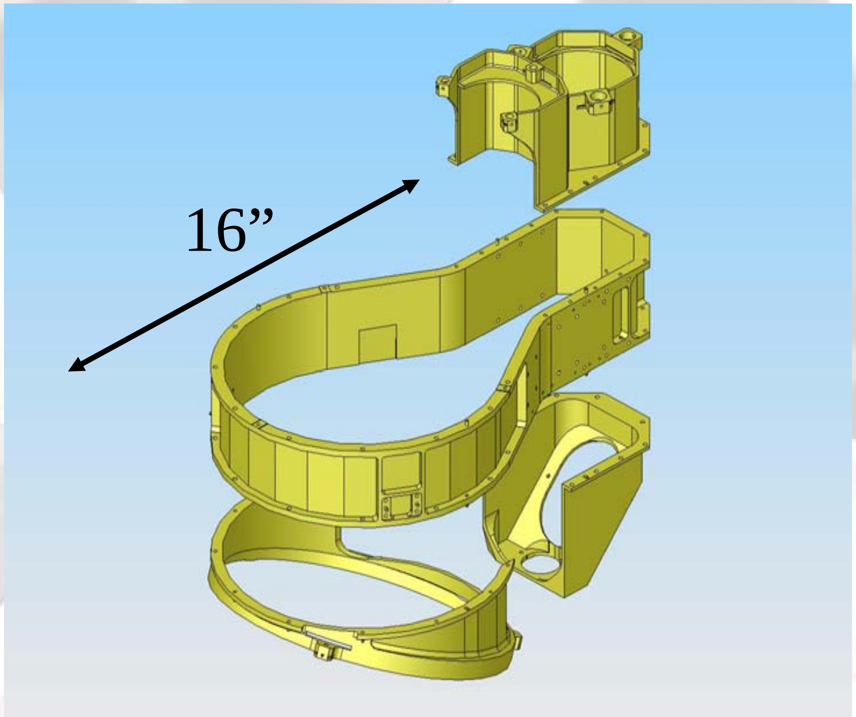
- Devise a preliminary design for an optical bench -- based on an existing Beryllium Bench design.
- Develop a manufacturing approach using the POCO SiC process
- Devise techniques for mounting SiC mirrors to SiC Bench/mount components.
- Estimate the cost and schedule savings compared to Beryllium

Innovative Research Issues:

- **Can a complex part such as an optical bench be produced from SiC?**
- **Can the number of Bench components be reduced thereby reducing mechanical interfaces and assembly complexity?**
- **How to mount and attach SiC to SiC to achieve an athermalized system?**
- **Does the manufacturing path have potential for cost and schedule savings?**

Design Approach:

- **Evaluate the Be design and convert to SiC design:**
  - **SiC is a Brittle material**
    - **Sharp corners, thin sections, etc.**
  - **CVC process poses some limitations**
    - **< 0.25” Wall thickness**
  - **Conversion Bonding allows some advantages**
    - **Combine components, reduce part count**
- **Address mounting issues – SiC mirrors on SiC bench.**

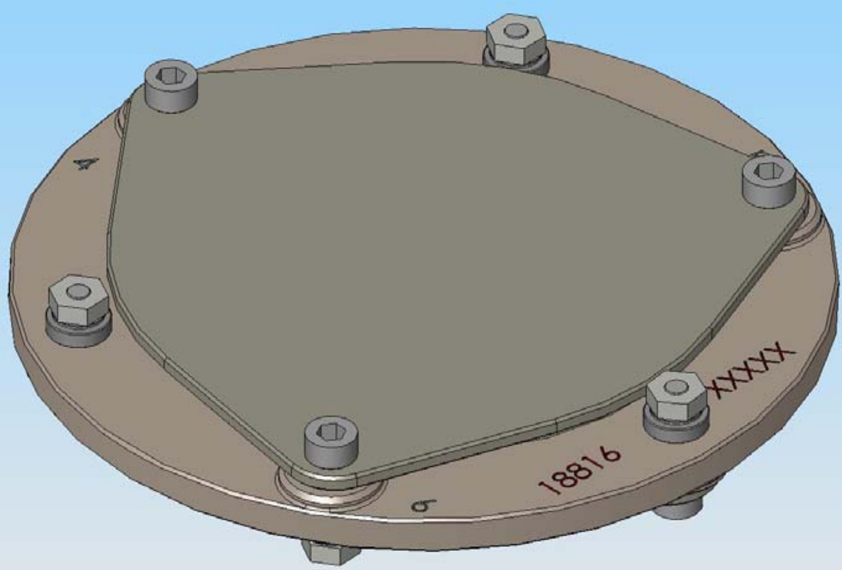


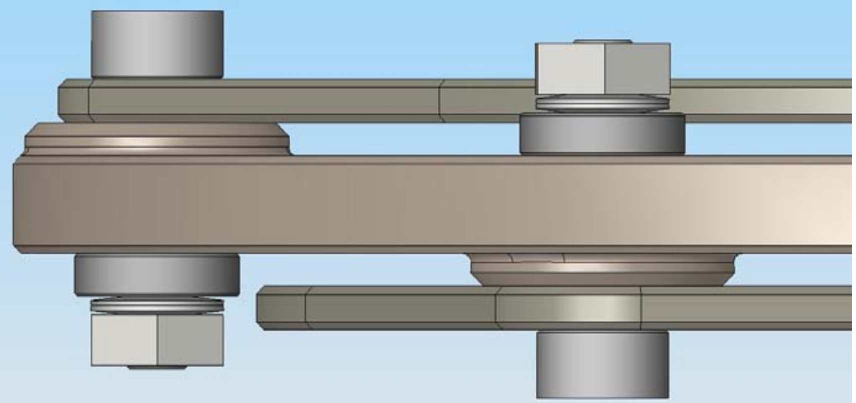
Be Design

Results of Preliminary Design Review

- **This component is a good candidate for SiC.**
- **It appears that the number of parts can be reduced using the CVC process**
- **Mirror mounting needs to be addressed.**
- **Design a flat test mirror and a mounting ring that will evaluate both clearance concepts.**

Proposed Test concept to Evaluate Mounting Concepts





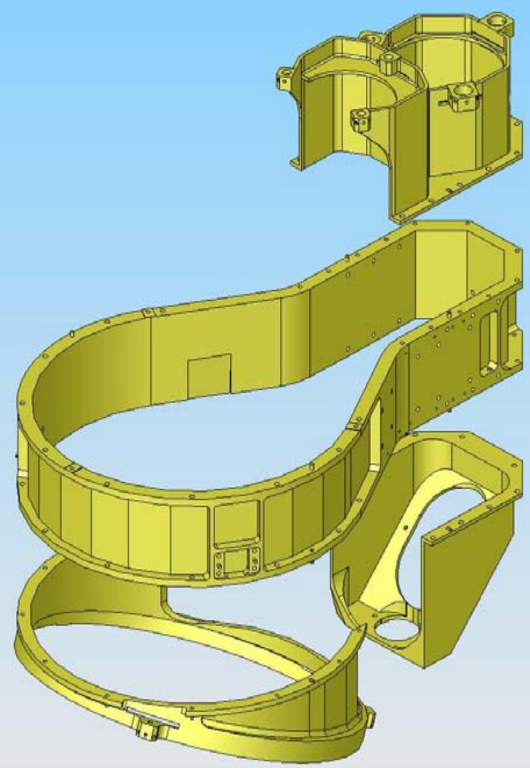
- Line to Line
- Float to Float

Test Fixture for Mounting of Mirrors

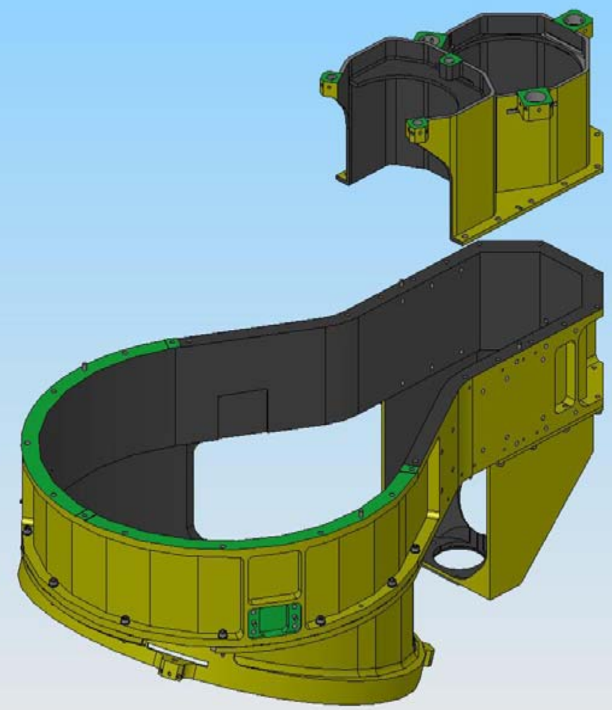
Results of Design Review

- Engineering and Manufacturing Reviews concluded that
  - Proper design requires re-engineering the part; it is more than a simple material substitution.
  - It is feasible to combine the three Beryllium Bench components into one SiC artifact
  - Bench Configuration simplified with two SiC vs. four original Be Components.
- Test Mount mirrors and rings were designed and manufacturing drawings created.
- Preliminary Schedule and cost review completed.

Resulting Simplified Design



Original 4 piece Beryllium



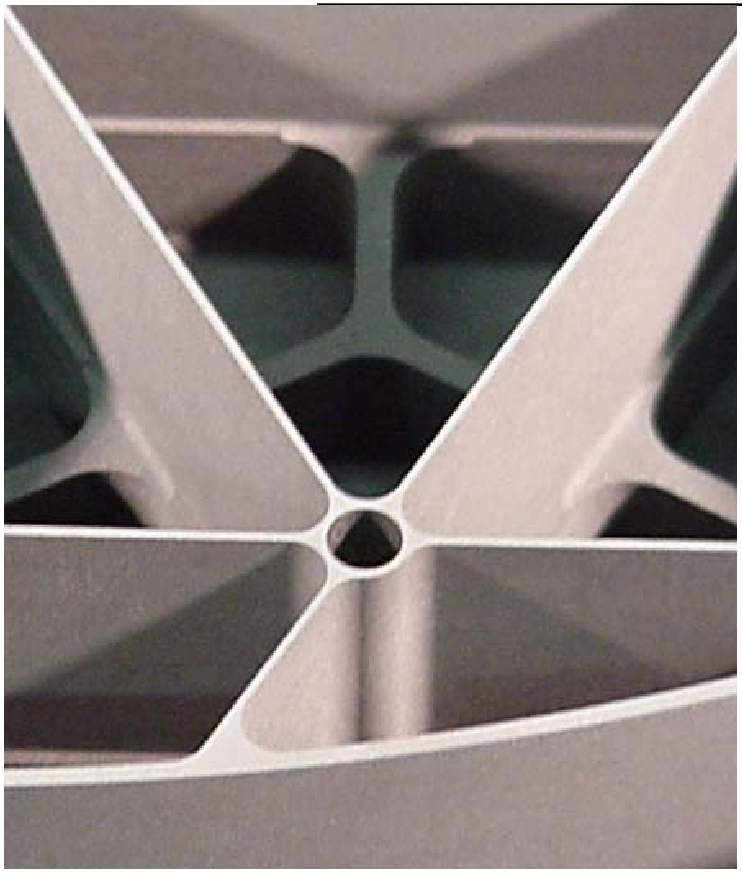
New POCO SiC Design

4 Be Components → 2 SiC Components

Future Work

- Test of mirror and mount attachment at cryogenic conditions.
- Dimensional Accuracy
  - Is CVD SiC coating & grinding required to achieve the necessary mounting pad accuracy?
- SiC Conversion
  - Investigate manufacturing process for large, complex structure-- effect of process variables on part distortion and warpage.
- Manufacturing of bench- Phase II.
  - Detailed design decisions for the Bench
  - Design for Manufacturing considerations
  - Capture actual cost and schedule.

Low-Cost Manufacture of Lightweight Mirror Systems



Focus on Finishing

Phase I SBIR

MDA – 086

Brett deBlonk AFRL

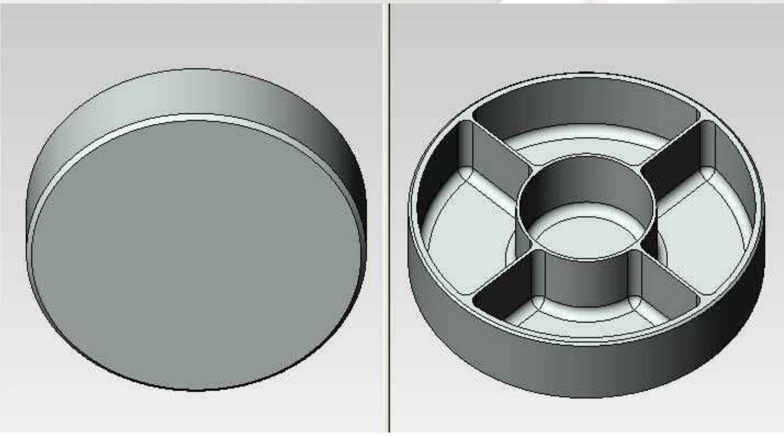
Space Vehicles Directorate

Background - Mirror Fabrication

- AFRL and MDA are looking for ways to reduce cost and lead-time for advanced optical systems-- driven by need for better optics and beryllium replacement.
- The target of this program is 0.3- 0.5 meter diameter mirrors.
- Silicon carbide mirrors have demonstrated excellent optical performance in cryogenic applications.
- POCO process can readily produce complex parts with little Silicon Carbide machining.

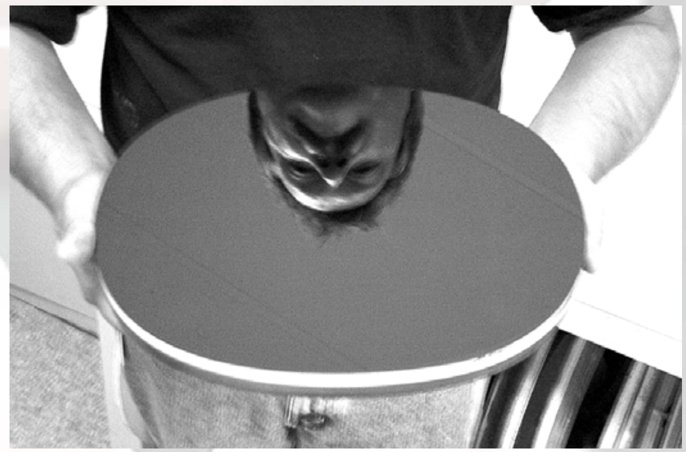
Approach for the Phase I contract

- **Objective- How to get from a POCO substrate to finished optical surface as quickly and as inexpensively as possible?**
  - **Survey technologies for optical finishing of SiC.**
  - **Gather estimates of performance, cost and schedule.**
  - **Demonstrate innovative processes on Test mirror.**
  - **Examine POCO process for improvements --synergy?**

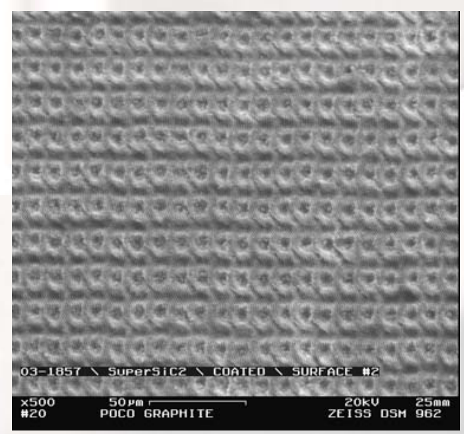


Candidate Finishing Technologies

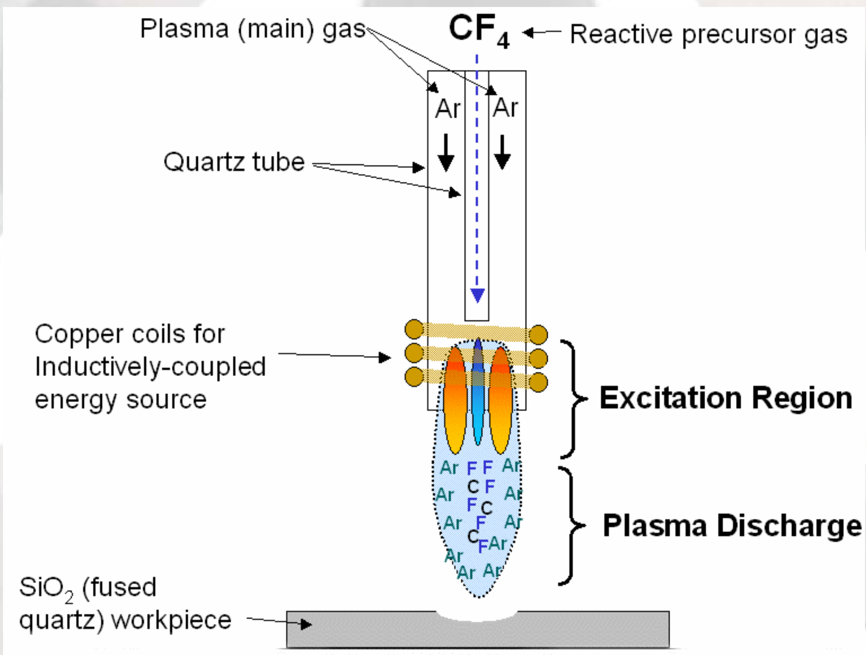
MRF- POCO SiC polished at Zygo using QED MRF to 1/10 wave and 10 A surface roughness.



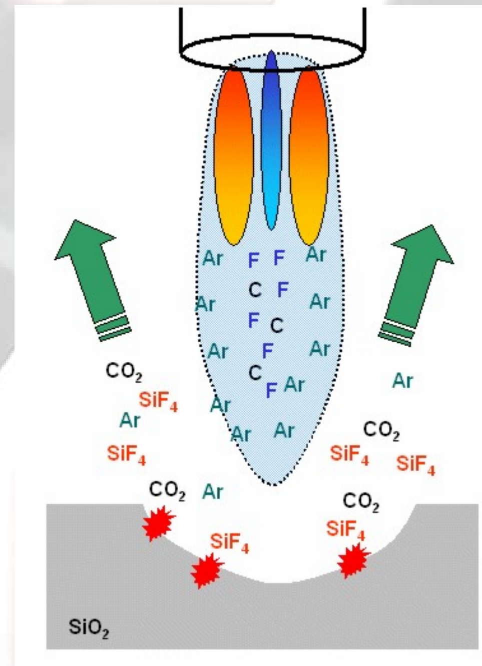
Laser machining on SiC-2 (CVD Coating). High Energy laser beam diameter is approximately 5-10 μm. (MLPC)



Reactive Atom Plasma



Schematic diagram of RAP tool. The reactive precursor gas is converted to highly reactive atomic radicals as it passes through the plasma excitation region.



RAP removes material by chemically converting the solid material to a gas.

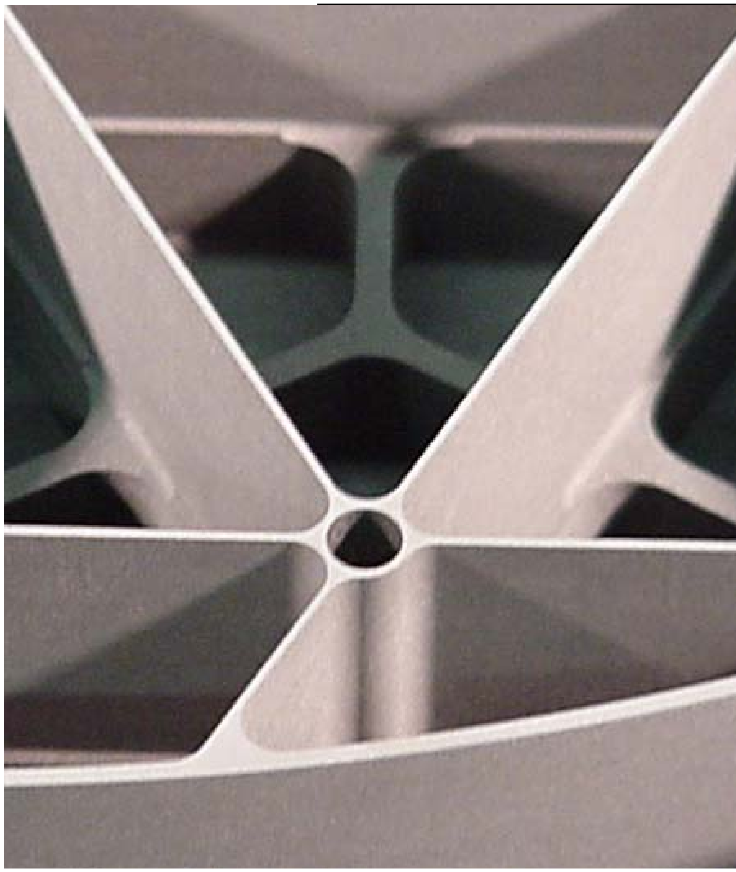
Effect of Tolerance Control on Machining Time

Improved Tolerance control in the CVC process can lead to reduced time and cost in polishing

Future Issues

- Test of mirror figure and roughness at common test site.
- Complex mirrors
  - Does technology transfer from flats to complex (off-axis asphere)
- Scale-up
  - Can technology produce 0.3-0.5 meter class mirrors and at what figure, roughness?
- Manufacturing / demonstration and test- Phase II.

Poco Data & Process Development



New Phase II

$1.2 million

MDA – 026

Brett deBlonk

AFRL – Space Vehicles Directate

Plus-up

- Plus-up – A Development contract to support Aerospace Optics
  - $1,200K Project: Congressional Add
  - Start August 23rd
- <u>Poco Goals:</u>
- Validate the SiC optical material – vs. Beryllium
- Data Development
  - COI and others
- Differentiate the Poco material/ process – Demonstrate that Poco has an advantage compared to competitive materials

Hurdles to SiC Use

- Data
  - Material - α, σ, ρ, E, k
  - Engineering – vibration, static, dynamic, acoustic
- Interface
  - Joining, mounting, attachments, bonding
- CVC Process Development
- Finishing
  - Figuring SiC: $\pm$ 0.001"
  - Polishing: < 10Å RMS, Flatness to λ/100
- Demonstrators
  - In real environment
- Cost and Schedule

Working with COI

Poco Investment in New Furnace

Working with other companies SBIR MDA 086

Material Testing

- Mechanical (Cryo, RT, HT)
  - Tension
  - Compression
  - Shear
  - Poisson's Ratio
  - Fracture Toughness
  - Notched Strength
  - Fatigue
- Thermal
  - CTE
  - Heat Capacity
  - Thermal Conductivity
  - Absorptivity
  - Emissivity
- Joints (Cryo, RT, HT)
  - Butt
  - T
  - Scarf
- Inserts
  - 2 concepts
- Stability
  - Creep, Long Term Stability
  - CTE variability (SRI)
  - Residual Stress - TBD method
  - Outgassing, etc
  - Radiation, Atomic Oxygen
- Static, Dynamic and Acoustic testing